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ABSTRACT

A major problem encountered by both teachers and authors of instructional materials is the sequencing of instructional activities. A review of the literature is given and it is pointed out that there is substantial evidence to support the general theory of the hierarchical structure of knowledge. A learning hierarchy for the computational skills for addition of rational numbers with like denominators was constructed. Based on the hypothesized ordering of the subordinate levels, a test was constructed to assess mastery at each level in the hierarchy; it was administered to 163 elementary school children in grades 4 through 6. The pass-fail relationships were analyzed using the following indirect validation procedures adaptable for use with test data: item difficulty, the AAAS approach, the Guttman technique, pattern analysis, and correlation analysis. Materials consisted of an 11-lesson programed booklet on the addition of rational numbers with like denominators. Fourth grade Ss were selected to participate in the study on the basis of their performance on two pretests. The hierarchical orderings of the 11 subtasks generated by each of the indirect validation procedures are given in tabular form. A pattern analysis technique was used to determine the index of agreement of each ordering with the expected patterns. This index was above .86 for all orderings except the textbook and random sequences. Neither planned nor post hoc comparisons showed any significant differences between the logical sequence group and the other sequence groups on achievement, transfer, or retention. Careful analyses of instructional objectives to reveal the prerequisite subtasks is an adequate procedure for developing a valid hiererchy. (CK)

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# VALIDATING LEARNING HIERARCHIES FOR SEQUENCING MATHEMATICAL TASKS

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A major problem encountered by both teachers and authors of instructional materials is the sequencing of instructional activities (Hartung, 1969; Hickey and Newton 1964; Gagne, 1967; Briggs, 1968; Heimer, 1969). Gagne (1963) stated that "the design of an instructional situation is basically a matter of designing a sequence of topics". Do optimal learning sequences exist? How are they determined, and how are they verified?

## RELATED LITERATURE

There is substantial evidence to support the general theory of the hierarchical structure of knowledge. Gagne and Brown, 1961; Gagne and Paradise, 1961; Gagne, Mayor, Garstens and Paradise, 1962; Gagne 1962; Gagne 1963; Gagne and staff, University of Maryland Mathematics Project, 1965 have demonstrated that new skills and knowledge emerge from lower order knowledge, and that there is a significant amount of positive transfer from each successive subordinate level to the next higher level in a hierarchical ordering of such levels.

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Evidence suggests that optimal learning sequences exist. Recent studies of sequencing (Niedermeyer, Brown & Sulzen, 1969; Brown, 1970) indicated that Ss using materials sequenced according to learning hierarchies performed reliably better than Ss using materials whose sequence was scrambled ralative to time to complete the instructional program, errors made on the program, and on a criterion test of complex problem solving skills. Brown (1970) concluded that when a sequence involves tasks that are complex problem solving behaviors ordering is an important factor in learning even for bright and relatively mature learners. In summarizing research on sequencing mathematical tasks Miller (1969) concluded that mastery of individual subtasks in a hierarchy can be achieved in several ways, including learning from randomly ordered sequences but that logical sequencing appeared best in terms of overall efficiency and effectiveness. Several studies (Roe, Case, and Roe, 1962; Levin and Baker, 1963; Payne, Krathwohl, and Gordon, 1967; Miller, 1965) suggest that varying sequences of instructional stimuli which have high interdependency does not make much difference in effectiveness of instruction. However, some of these studies are plagued with design problems. Before sequencing instructional materials in mathematics for use in classrooms the effects of sequence upon time to achieve the terminal behavior, achievement, transfer, and retention should be investigated.

That sequence is a critical variable in learning has been suggested by many learning theorists (Ausubel, 1963; Bruner, 1964; Gagne, 1965; Glaser, 1964; and Suppes, 1966). However, both

Gagne (1968) and Pyatte (1969) have pointed out that determining the hierarchical ordering of subtasks from simplest to most complex is still a major problem. Gagne's (1962) approach to learning hierarchy validation by means of trial and error is tedious and costly. While its validity is not questioned, it is unlikely that classroom teachers or authors of instructional materials will validate hierarchies in such a manner. If instructional materials are to be improved by hierarchical analyses, a less expensive procedure for validating hierarchies is needed.

The Guttman technique (Torgerson, 1958), pattern analysis (Rimoldi & Grib, 1960) and the AAAS method (AAAS Commission on Science Education, 1968) appear to be adaptable for validating deductively analyzed hierarchies using test data. Other procedures based on the correlation between test items or levels of the hierarchy and the difficulty of items could be useful in validating a hierarchy using test data. The present study was designed to examine the adequacy of each of these procedures for validating a learning hierarchy using test data by sequencing instructional materials according to the hierarchy generated by each procedure comparing achievement, transfer, retention and time to complete the instructional sequences.

## METHOD

### Development and Analyses of the Hierarchy

Using Gagne's task analysis a learning hierarchy for the computational skills for addition of rational numbers with like denominators was constructed. The sequence of subtasks generated was reviewed by four authors of elementary mathematics texts. Based upon their evaluation of the adequacy and completeness of the hierarchy, the sequence of subtasks was revised until there were no obvious flaws in

the learning hierarchy. Based on the hypothesized ordering of the subordinate levels, a test was constructed to assess mastery at each level in the hierarchy. The test was designed to minimize chance or careless errors. A procedure of test construction similar to the "H-technique" (Stouffer, Borgatta, Hays, and Henry, 1952) was adopted. The test consisted of composite test items for each level in the hierarchy. Each composite item consisted of three items testing the same subordinate task. Pass at each level was defined as correct responses to at least two of the three items for that level. The entire test consisted of 11 composite items making a total of 33 items. The internal consistency of the test was determined using the Kuder-Richardson Formula 20 (Nunnally, 1967).

The test was administered to 163 elementary school children in grades 4 through 6 to obtain a sufficiently wide range of ability levels. The test was administered by the classroom teachers and was completed by all Ss in one sitting although it was not timed. Ss were instructed to attempt all items and were given sufficient time to do so.

The pass-fail relationships were analyzed using the following indirect validation procedures adaptable for use with test data.[1]

(1) Item difficulty (Nunnally, 1967)

(2) The AAAS approach (AAAS Commission on Science Education, 1968)

(3) The Guttman technique (Torgerson, 1958)

(4) Pattern analysis (Rimoldi and Grib, 1960)

(5) Correlation analysis (Phillips, 1971)

For comparative purposes the 11 subtasks were also ordered according to the "usual" textbook sequence and for a control they were randomly ordered. Thus, 7 different orderings of the 11 subtasks were generated.

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1. For detailed description of these validation techniques, see Phillips, 1971.

## Instructional Materials

The materials used in this study consisted of an eleven-lesson programmed booklet on the addition of rational numbers with like denominators. The program utilized one lesson for each of the 11 levels in the learning hierarchy. Each of the 11 lessons was designed to develop the specific skill represented by the corresponding hierarchy level. The lessons were from 2 to 3 pages in length, making a total program length of 29 pages. The program evoked frequent responses from S which he wrote in blanks provided. Care was taken to minimize the reading load. While lessons were presented in seven different orders from the exterior all seven forms of the instruction booklet appeared the same.

## Experimental Procedures

Fourth grade Ss were selected to participate in the study on the basis of their performance on two pretests. Pretest I was designed to determine if the learners had mastered the necessary prerequisites for successfully achieving the skills presented in the programmed text. The test concentrated on the concept of fraction, recognizing parts of a whole, reading and writing fractional numerals, whole number addition, and simple whole number division. Pretest I was administered to 175 Ss one week prior to initiation of the learning sequence. Pretest II was administered only to those students judged, on the basis of Pretest I, ready to undertake the programmed materials.

Pretest II was designed to determine if the students had already mastered the skills to be taught in the instructional sequence. The test consisted of one item for each of the 11 levels in the hierarchy.

Only those subjects judged, on the basis of Pretest II, to have mastered an insignificant number of the skills in the instructional program were included in the study.

Ss were assigned randomly to treatment groups. They worked through the programmed booklets independently devoting approximately 30 minutes per day to the materials until they were completed. E explained how to use the materials and assisted Ss with any problems they encountered for the first two days of the study. Thereafter the teachers supervised Ss' work until completion of the study.

Ss entered their responses to questions directly in the booklets using a cardboard cover-up for the answer column. Subjects were instructed to keep the answer column covered until they entered their response then pull the cardboard down to reveal immediately the correct response. If their response was incorrect and they could not determine the source of their error, they were instructed to ask the teacher for help. Teachers were instructed to give help only in the context of each child's material. For instance, if one child's sequence had a frame which involved writing the simplest name for fractional numerals but no frame preceding dealt with the definition of simplest name or the mechanics of renaming, the teacher did not show the student the manipulations involved in renaming. The students were to be guided in using only the information and art work provided in the given frame.

The teachers kept a log book of the exact number of minutes spent on the booklets each day. As each child finished his booklet, the date and time of completion were entered in his booklet. Thus allowing for determining the total number of minutes each student spent in completing the programmed materials. In order to discourage Ss from rushing through

the materials, they were reminded at the beginning of each session that they were to study the materials and try to remember what they did, not just copy in the correct responses. They were also told that they would be tested upon completion of the booklet. For the duration of the study, Ss had no mathematics class other than the work session on the programmed booklets. Since they finished the booklet at differing times, teachers had other unrelated mathematics activities for each Ss to do until the whole group had finished.

An achievement test designed to measure acquisition of the terminal task - addition of rational numbers with like denominators-was administered on the day following completion of the programmed sequence. The test consisted of two items per level in the hierarchy (lessons in the programmed materials) except for two levels which pertained to renaming. An alternate form of this test was administered two weeks later as a retention test. During these two weeks Ss studied mathematical topics other than operations with fractions. A transfer test on subtraction of rational numbers with like denominators was administered on the day following administration of the achievement test. This test consisted of 10 items of skills analogous to those found in the learning program on rational number addition. Reliability coefficients for all tests were determined by the Kuder-Richardson Formula 20 (Nunnally, 1967). Analysis of variance for multiple groups, unequal n's model, (Winer, 1962) was used to investigate the differential effects of sequencing on four variables: achievement, transfer, retention and time (total number of minutes to complete the programmed booklet.)

## RESULTS OF THE STUDY

### Hierarchical Analyses

The hierarchical orderings of the 11 subtasks generated by each of the indirect validation procedures are given in Table 1. A pattern analysis technique (Rimoldi and Grib, 1960) was used to determine the

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Insert Table 1 about here

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index of agreement of each ordering with the expected patterns. This index was above .86 for all orderings except the textbook and random sequences. These were .62 and .61 respectively.

### Pretests

Ss were selected on the basis of their performance on two pretests. Pretest I was designed to answer the question "Does S have the necessary prerequisite skills needed to master the skills presented in the learning program?" Pretest II was designed to answer the question "How many of the skills presented in the learning program has the learner already mastered?" An acceptable score on Pretest I was defined as one ranging between 24 and 17 on a 24 point test; for Pretest II between 0 and 4 on an 11 point test. Of the 175 Ss tested, 142 met the criterion on both tests. Eighty-seven percent of the subjects included in the study obtained scores on Pretest I of 20 or higher with 23% having perfect scores. Only 13% of the subjects gave incorrect responses to 5 or more items. The mean score on Pretest I was 21.84. Seventy-one of the subjects tested were unable to respond correctly to any of the 11 items on Pretest II. Ninety-two percent of the subjects gave correct responses to less than 3 of the 11 items. The mean score on Pretest II was 0.563.

The Effects of Sequence

The differential effects of sequence upon achievement, transfer, retention, and time to complete the program were investigated using an analysis of variance design. The internal consistency coefficients (KR-20) for each test used was greater than .90. One-way analyses of variance on achievement, transfer, retention, and time are shown in Tables 2,3,4,5, respectively.

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Insert Tables 2,3,4,5 about here

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No overall significant differences were found at the .05 level. However, the F-ratio of 2.12 for the analysis of variance on retention was very near the critical value 2.15. Post-hoc comparisons of all means using the Duncan Multiple Range Test (Winer, 1962) showed statistically significant differences at the .05 level between the AAAS sequence group (8.52) and both the textbook (4.95) and the item difficulty (5.37) sequence groups.

Further Investigations of Sequence Effects

Examination of the tests revealed that many low scoring Ss had actually mastered the skills involved in rational number addition. However, due to not following directions or having not mastered the skills involved in renaming they failed to write answers in simplest form. In view of this two other scoring procedures were used. The first of these alternative scorings gave one-half credit for responses which were correct but not reduced to lowest terms. The second alternative gave full credit for responses which were not in lowest terms but otherwise correct. One-way analyses of variance on achievement using the alternative scoring procedures are shown in Tables 6 and 7. No overall significant differences were found in either case.

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Insert Tables 6,7 about here

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One-way analysis of variance on transfer allowing partial credit in scoring is shown in Table 8. The differences among treatment means was not significant at the .05 level. One-way analysis of variance on transfer disregarding reduction to lowest terms in scoring is shown in Table 9. The F-ratio was significant at the .05 level. The Duncan Multiple Range Test indicated significant differences at the .05 level between two pairs of means, that of the random sequence group (5.26) and both the phi coefficient sequence group (5.10) and the textbook sequence group (5.19).

One-way analyses of variance on retention using the alternative scoring procedures are shown in Tables 10 and 11 respectively. In the first case F was near the critical value at the .05 level. The Duncan Multiple Range Test indicated significant differences between two pairs of means. The AAAS sequence group mean was significantly greater than that of both the item difficulty and the textbook sequence groups. When

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Insert Tables 8,9,10,11 about here

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disregarding reduction to lowest terms, the F-ratio was significant at the .05 level. Significant differences between two pairs of means were found using the Duncan test. The AAAS sequence group mean was significantly greater than those of both the item difficulty and the textbook sequence groups.

## DISCUSSION AND CONCLUSIONS

The reader's attention was directed toward two troublesome problems with many studies of the effects of sequence reported in the literature. First, in comparing the effects of a logical and a random sequence upon learning, it was not demonstrated that indeed a logical sequence and an

unbiased random sequence were being used. Second, in many of the studies reported, it was suspected that too many of the subjects already knew much of the material presented in the learning program. This study was designed to minimize the possibility of these pitfalls.

The index of agreement was used to determine if the hypothesized ordering developed through the use of task analysis was indeed logical. That is, that it was hierarchical in structure. The index of agreement was .87 which indicated that the observed response patterns of the subjects correlated highly with the expected patterns indicating that the logical ordering was logical. The index of agreement for the random order was .61. Thus, the logical ordering appeared to have markedly more of the characteristic of hierarchical structure than did the random ordering. With the exception of the textbook ordering all other sequeces were validated empirically using various procedures. The indices of agreement for all validated orderings were above .85 indicating high correlations between observed and expected response patterns. The index of agreement for the textbook ordering was only .62 however.

Subjects included in the study had to meet stringent criteria on two pretests. Namely, they had to have the necessary prerequisites for undertaking study of the skills presented in the instructional program, and they could not have already mastered the skills to be taught. Thus, the probability was very low that outcomes attributed to sequence were affected by inadequate entering behaviors or by prior knowledge of the material to be learned.

On the other hand due consideration must be given to two sources of artifact over which we had less control than would have been desireable.

1. Teachers were instructed on the type and amount of help to provide. However, they reported that Ss in some sequence

groups who were asked to perform certain tasks when they had not mastered necessary prerequisites were very frustrated. In these instances, the teachers may have provided too much instruction making assessment of sequential effects difficult. This could have accounted for the absence of significant differences among the mean achievement scores of the seven sequence groups.

2. Examination of Ss responses revealed that many students did not write answers in lowest terms. Again, the teachers were instructed to stress directions and be sure all learners understood what was expected of them. Thus, it might be concluded that the lessons pertaining to reducing to lowest terms were not adequate. However, when allowing partial credit or disregarding reducing to lowest terms in scoring, still no significant differences were found on immediate achievement.

Neither planned nor post hoc comparisons showed any significant differences between the logical sequence group and the other sequence groups on achievement, transfer, or retention. The logical sequence group did require significantly less time to complete the program than did the correlational sequence group. This suggests that careful task analysis of instructional objectives can be a powerful tool in devising optimal instructional sequences. In fact it may mean that in terms of overall cost, that careful analyses of instructional objectives to reveal the prerequisite subtasks is an adequate procedure for developing a valid hierarchy.

Within the limitations of this study the results seem to justify the following conclusions:

1. The overall efficiency of the learning process, using programmed instructional materials, can be affected by changing the sequential ordering of the subtasks.
2. Sequence, even if random, has little effect upon immediate achievement.
3. Retention appears to be the variable, of the four under study, most susceptable to sequence manipulation.
4. No sequence maximally facilitated achievement, retention, and transfer, and required less time to complete. However, based on the group means, the AAAS procedure yielded the best sequence overall.
5. Textbook authors may need to give more careful consideration to the sequencing of subtasks within major topics or subdivisions of a chapter.
6. Optimal instructional sequences can be derived using learning hierarchies validated from test data.

The effects of sequence should be investigated by replications with more complex skills involving longer learning sequences and larger samples. Further research should attempt to determine the effects of sequence upon attitudes and anxieties experienced by learners in different sequence groups, the interaction effects between sequence and ability, and the effects of sequence upon immediate achievement, transfer, and long term retention. The effects of carefully sequenced instructional materials according to validated learning hierarchies on the performance of the slow learner and the remediational value of such instructional sequences should be investigated thoroughly.

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Table 1. Hierarchical orderings generated by each indirect validation procedures.

| | Procedures | | | | | |
|---|---|---|---|---|---|---|
| Logical (task analysis) (1) | Guttman (2) | Random (3) | Item Difficulty (4) | Correlation (Phi coefficient) (5) | Textbook (6) | AAAS (7) |
| 1 | 2 | 3 | 1 | 1 | 5 | 1 |
| 2 | 1 | 6 | 2 | 2 | 9 | 2 |
| 3 | 4 | 2 | 4 | 4 | 3 | 4 |
| 4 | 3 | 7 | 3 | 3 | 1,2 | 3 |
| 5 | 5 | 1 | 5 | 5 | 6 | 5 |
| 6 | 6 | 10 | 6 | 8 | 4,7,8 | 6 |
| 7 | 8 | 8 | 8 | 7 | 10,11 | 7 |
| 8 | 7 | 5 | 7 | 6 | | 9 |
| 9 | 9 | 4 | 9 | 9 | | 10 |
| 10 | 10 | 11 | 10 | 11 | | 8 |
| 11 | 11 | 9 | 11 | 10 | | 11 |

LEVELS

Table 2. One-way analysis of variance on achievement.

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 18.83 | 6 | 1.45 | .1992 |
| Experimental error | 12.98 | 135 | | |

Group Means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 6.23 | 4.84 | 6.47 | 5.21 | 6.05 | 5.14 | 7.62 |

Table 3. One-way analysis of variance on transfer.

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 11.30 | 6 | 1.43 | .2051 |
| Experimental error | 7.88 | 135 | | |

Group Means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 5.05 | 4.63 | 5.26 | 3.95 | 3.67 | 3.57 | 5.24 |

Table 4. One-way analysis of variance on retention.

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 33.61 | 6 | 2.12 | .0542 |
| Experimental error | 15.84 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 7.50 | 7.32 | 6.89 | 5.37 | 7.62 | 4.95 | 8.52 |

Table 5. One-way analysis of variance on time.

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 2931.20 | 6 | 1.96 | .0757 |
| Experimental error | 1498.99 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 103.86 | 101.95 | 114.16 | 126.11 | 135.33 | 117.24 | 122.86 |

Table 6 . One-way analysis of variance on achievement (partial credit).

| Source of variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 43.21 | 6 | 1.688 | .1278 |
| Experimental error | 25.60 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 9.64 | 7.42 | 9.89 | 7.05 | 8.67 | 7.81 | 11.05 |

Table 7 . One-way analysis of variance on achievement (reducing disregarded).

| Source of variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 71.43 | 6 | 1.70 | .1259 |
| Experimental error | 42.12 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 11.91 | 9.68 | 13.05 | 8.47 | 11.00 | 11.10 | 14.05 |

Table 8 . One-way analysis of variance on transfer (partial credit)

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 19.97 | 6 | 1.89 | .0870 |
| Experimental error | 10.59 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 6.27 | 5.89 | 6.89 | 5.00 | 4.76 | 4.52 | 6.86 |

Table 9 . One-way analysis of variance on transfer (reducing disregarded).

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 31.43 | 6 | 2.17 | .0465 |
| Experimental error | 14.31 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 7.05 | 6.84 | 8.26 | 5.95 | 5.10 | 5.19 | 7.86 |

Table 10. One-way analysis of variance on retention (partial credit).

| Source of Variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 56.32 | 6 | 2.14 | .0525 |
| Experimental error | 26.35 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 10.91 | 10.26 | 9.70 | 7.84 | 10.81 | 7.57 | 12.10 |

Table 11. One-way analysis of variance on retention (reducing disregarded).

| Source of variation | MS | df | F | P |
|---|---|---|---|---|
| Treatments | 95.08 | 6 | 2.25 | .0416 |
| Experimental error | 42.24 | 135 | | |

Group means

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 14.23 | 12.84 | 12.53 | 9.68 | 13.90 | 10.00 | 15.48 |